RECLAMATION

Managing Water in the West

Evaluating Fiber Reinforced Concrete for Use in Canal Construction and Canal Repairs

Research and Development Office
Science and Technology Program
ST-2017-1795-01 (8530-2017-40)

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Final Report ST-2017-1795-01

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Acronyms and Abbreviations

ACI	American Concrete Institute
FRC	Fiber Reinforced Concrete
O&M	Operations and Maintenance

Executive Summary

Reclamation has used concrete canal linings for more than 50 years. Fiber reinforced concrete (FRC) has been studied since the 1960's. Reclamation has used fiber reinforced concrete in some of its canal linings. FRC affords many advantages to Reclamation provided it is used in the correct application and manufactured and installed correctly. Some of the advantages include possible reduction in concrete thickness needed due to the matrix being stronger than unreinforced concrete; reduction in cracks and control of cracks that do form; resistance to impact and abrasion; reduced maintenance costs and longer service life.

New fiber technology has made it necessary to revisit the use of FRC in canal structures. These fibers can now be used to reduce conventional reinforcing and provide a structural slab which can carry larger loads. Today's fibers do more than reduce the potential for early age plastic shrinkage cracking as originally designed.

Reclamation should study the use of the new fiber and mix design technology to determine if FRC canal linings should be more widely specified.

Contents

Tables

Figures

Introduction

Approximately 6,600 hundred miles of canals have been constructed by Reclamation since the early 1900's. Approximately 57% of those canals were lined with concrete. The use of concrete lining provides for better hydraulic characteristics, including steeper side slopes, which can result in a smaller canal prism [1]. Concrete lined canals can also deter burrowing animals and allow for higher flows. Concrete lined canals can be more expensive to construct due to potential for extensive subgrade treatment or underdrain installation. Some Reclamation canals have been constructed with reinforcement, either traditional or fiber, but most are unreinforced concrete.

Fiber reinforced concrete (FRC) has existed since ancient times. Originally, animal hair was used as reinforcement. In the early 1900s, asbestos fibers were added to concrete. With the advent of composite materials in the 1950s, fiber reinforced concrete began to be looked at more closely. This interest in FRC has continued to today with various materials being used such as natural, glass, steel and synthetic fibers. Research continues to be conducted on new materials and uses for FRC.

There have been numerous studies on fiber reinforced concrete, its properties and applications. These studies have been conducted by product manufacturers, government entities, universities and private industry and they have provided insight and knowledge into FRC. FRC has changed over the past 5 years with regard to fiber material type, size and geometry. These properties have not been evaluated as completely as the original studies on micro fibers. New testing procedures have been developed that better replicate field use conditions.

Unreinforced concrete has a low tensile strength and a low strain capacity at fracture [2]. Reinforcing is used to overcome these issues. Unlike traditional reinforcing, fibers are not continuous through the structure and are distributed randomly throughout the concrete.

There are two basic sizes of fibers being used today. They include micro and macro fibers. Macro fibers are also known as structural fibers which are intended to carry loads and can potential replace some reinforcement. Macro fibers are typically 1.5" long or longer. Micro fibers are less than 1.5" in length and are traditionally used to reduce early age plastic shrinkage cracking and cannot be used to replace traditional reinforcement. Macro fibers are traditionally made from steel or glass while micro fibers are traditionally polypropylene.

Examples of fiber types and sizes can be seen below.

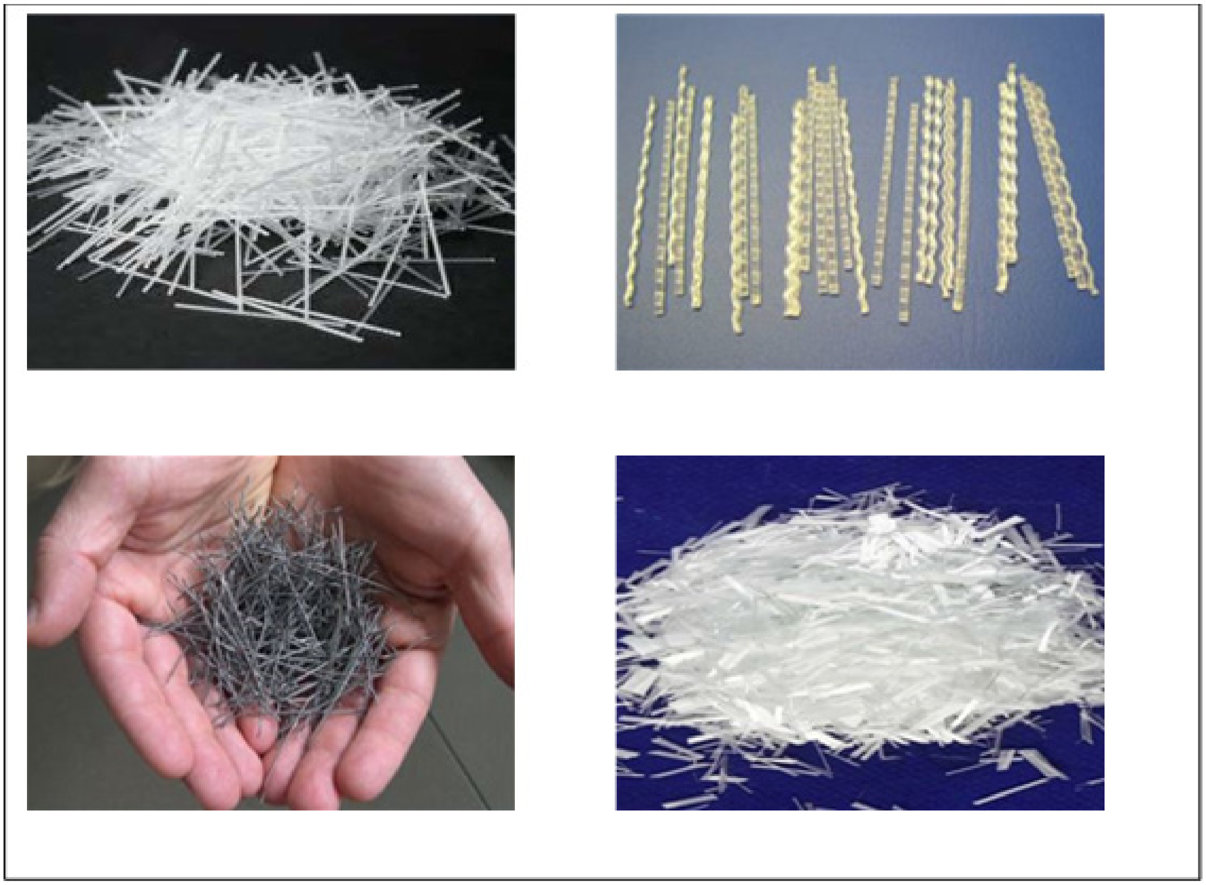

Figure 1. Types of Fibers.

Classes of Fiber Reinforced Concrete

Fiber reinforced concrete is classified based on the fiber material used. ASTM C1116/C1116M-10a (2015) *Standard Specification for Fiber-Reinforced Concrete* [3] lists four classes of fiber reinforced concrete. Those classes are:

A. Type 1 Steel Fiber-Reinforced Concrete: Contains stainless steel, alloy steel, or carbon steel fibers.
B. Type II Glass Fiber-Reinforced Concrete: Contains alkali-resistant (AR) glass fibers.
C. Type III Synthetic Fiber-Reinforced Concrete: Contains synthetic fibers which are documented to be resistant to deterioration when in contact with moisture and alkalis present in cement paste. Polypropylene and polyethylene, nylon and carbon fibers have been shown to be durable in concrete.
D. Type IV Natural Fiber-Reinforced Concrete: Contains natural fibers documented to be resistant to deterioration to be resistant to deterioration when in contact with the moisture and alkalis present in cement paste.

Table 1 lists the materials and properties of various types of fibers.

Table 1. Selected Fiber types and properties [2].

Fiber type	Equivalent diameter, in. × 10^{-3}	Specific gravity	Tensile strength, ksi	Elastic modulus, ksi	Ultimate elongation, percent	Ignition temperature, °F	Melt, oxidation, or decomposition temperature, °F	Water absorption per ASTM D 570, percent by weight
Acrylic	0.5-4.1	1.16-1.18	39-145	2000-2800	7.5-50.0	—	430-455	1.0-2.5
Aramid I	0.47	1.44	425	9000	4.4	high	900	4.3
Aramid II†	0.40	1.44	340	17,000	2.5	high	900	1.2
Carbon, PAN HM‡	0.30	1.6-1.7	360-440	55,100	0.5-0.7	high	752	nil
Carbon, PAN HT§	0.35	1.6-1.7	500-580	33,400	1.0-1.5	high	752	nil
Carbon, pitch GP**	0.39-0.51	1.6-1.7	70-115	4000-5000	2.0-2.4	high	752	3-7
Carbon, pitch HP††	0.35-0.70	1.80-2.15	220-450	22,000-70,000	0.5-1.1	high	932	nil
Nylon‡‡	0.90	1.14	140	750	20	—	392-430	2.8-5.0
Polyester	0.78	1.34-1.39	33-160	2500	12-150	1100	495	0.4
Polyethylene‡‡	1.0-40.0	0.92-0.96	11-85	725	3-80	—	273	nil
Polypropylene‡‡	—	0.90-0.91	20-100	500-700	15	1100	330	nil

*Not all fiber types are currently used for commercial production of FRC.
†High modulus.
‡Polyacrylonitrile based, high modulus.
§Polyacrylonitrile based, high tensile strength.
**Isotropic pitch based, general purpose.
††Mesophase pitch based, high performance.
‡‡Data listed is only for fibers commercially available for FRC.
Metric equivalents: 1 in. = 25.4 mm; 1 ksi = 6.895 MPa; (degrees F - 32)/1.8 = degrees C.

Fiber Geometry

Fibers can be produced in an infinite variety of shapes and sizes [4]. Dr. Zollo describes these geometries as:

A. Prismatic: rounded or polygon cross-section with smooth surface or deformed throughout or only at the ends.
B. Irregular cross-section: cross-section varies along the length of the fiber.
C. Collated: multifilament (alternatively termed branching or fibrillated) or monofilament networks (or bundles) that are usually designed to separate during FRC production (mixing).

Specific production techniques allow almost any fiber geometry and a wide range of fiber amount, usually specified as a volume percent of the total composite, to be placed.

Benefits of Using Fiber

Fiber use in slabs on ground can afford many benefits to a project. There is a potential time savings since reinforcing steel or welded wire fabric will have to be installed. Potential lower O&M costs for canals using FRC since the fiber will increase the durability of the concrete versus placing plain concrete. Potential crack width reduction or elimination which may result in less water being lost from the canal.

Polypropylene fibers can improve mix cohesion, freeze thaw resistance, spalling resistance, plastic shrinkage cracking and ductility. Steel fibers can improve structural strength, reduce conventional reinforcement, and reduce crack widths.

ACI 544.1 [2] states that "fibers may also enhance the properties [of concrete] including tensile strength, compressive strength, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion shrinkage, expansion, thermal characteristics, and fire resistance." Fibers can also increase the toughness of concrete which is the measure of the energy absorption capacity of the material.

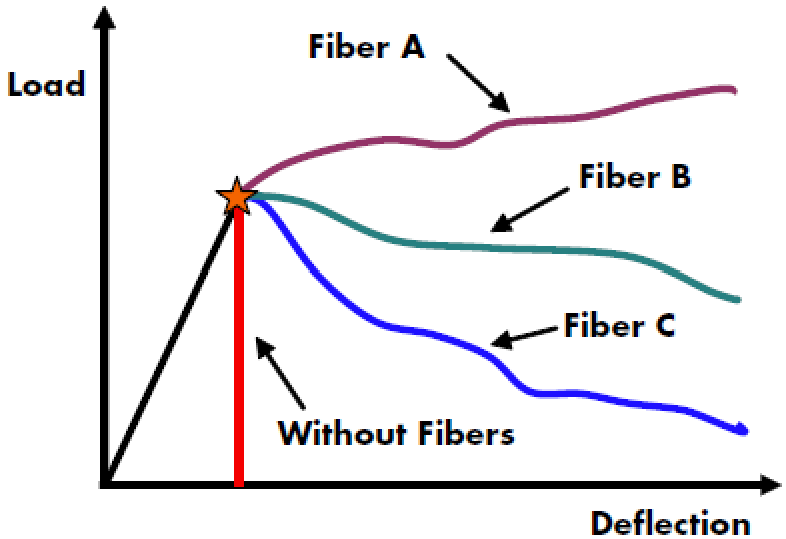

Figure 2. Concept of Toughness [5].

Figure 2 illustrates four different scenarios of concrete that either includes or does not include fibers. The FRC samples have higher load bearing capacity after initial cracking. The specimen that was not fiber reinforced broke in half after cracking. If the concrete matrix is held together after cracking or sustaining damage, a canal can still be utilized until such time as a repair can be made and piping failure are less likely to occur. The toughness may also prevent some water loss thus increasing the amount of water delivered to the end user.

Next Steps

Reclamation has utilized fiber reinforced concrete in the past for canal linings. To the author's knowledge, recent testing using new fiber technology and mix design techniques has not been undertaken by Reclamation. While FRC has been in existence for 40 years, the advent of new fiber materials, sizes and shapes has not been utilized on canal structures within Reclamation. Reclamation should conduct trials on these new materials to verify if they can be utilized in Reclamation canal structures. The materials may allow for thinner sections to be installed and offer the potential for increased canal service life and reduced O&M costs.

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